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(54) Slotted waveguide antennas and arrays.

(57) Array antennas constructed from some forms of waveguide radiators with sidewall slots exhibit cross polarisation and periodic errors. This problem arises from the difficulty of obtaining phase reversal in the radiation from adjacent slots in such a radiator other than by slot inclination. The present invention offers two solutions. Firstly, a radiator 10 having a number of non-inclined sidewall slots such as 13 and 14 and a septum 15 with inclined slots such as 25 and 26 which provide a phase relationship in the radiation from the sidewall slots which ensures that no significant cross polarisation errors nor grating lobes occur. A number of radiators 10 can be used to form an array. Secondly, arrays using radiators with sidewall slots, in which the distance between these slots, the dimensions of the radiators and the relative positions of individual radiators are such that the phase relationship in radiation from the slots of the array prevent significant grating lobes.

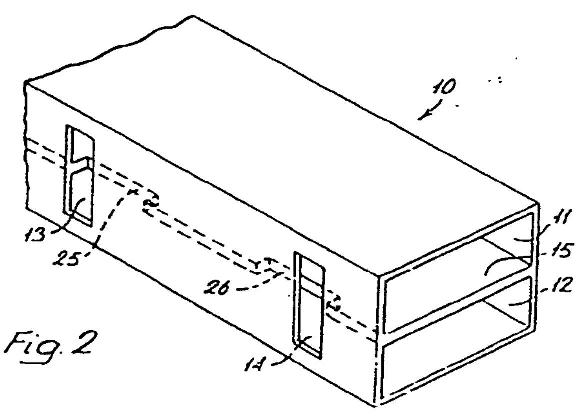

Fig. 2

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SLOTTED WAVEGUIDE ANTENNAS AND ARRAYS

The present invention relates to slotted waveguide antennas employing waveguide radiators having sidewall slots and arrays of such radiators.

The merits of slotted-waveguide array antennas, which are capable of providing well controlled, very low side lobe, radiation patterns, are well known. For linearly polarised arrays two methods of slotting the waveguide are commonly used: namely staggered axial shunt slots in the broad wall, or inclined sidewall slots. Unfortunately arrays formed from slots of this type suffer from two basic radiation pattern errors. These are firstly periodic errors associated with the requirement either to stagger the longitudinal shunt slots or to incline the sidewall slots oppositely, and secondly cross-polarisation errors particularly in the case of the sidewall slots because of their inclination.

Where sidewall slots are used, the slots should be normal to the longitudinal axis of the waveguide in order to prevent cross-polarisation. The slots should also be symmetrical with regard to longitudinal axis to avoid periodic errors. The latter requires means inside the waveguide to ensure that radiation from the symmetrical slots occurs.

The radiation patterns of waveguides with symmetrical sidewall slots contain grating lobes because adjacent slots radiate in phase only when separated by a distance equal to one or more wavelengths of the mode within the waveguide and it is an object of the present invention to provide in phase radiation when the sidewall slots are separated by half of the guide wavelength.

According to a first aspect of the present invention there is provided an elongated waveguide radiator which in cross section is divided into first and second waveguide portions by a septum, having a plurality of first elongated slots in an external wall of the radiator each of which extends on both sides of the septum and is orthogonal to the longitudinal axis of the radiator, and a plurality of elongated second slots, each of which extends from a

corresponding one of the first slots into the septum, and has a longitudinal axis which is inclined to a line in the septum normal to the longitudinal axis of the radiator, the direction of the angle of inclination alternating along the radiator.

The inclination of the second slots can be as required to provide a desired control of the radiation magnitude from adjacent slots but the second slots must be inclined to said line in the septum (that is second slots must not be parallel to the longitudinal axis of the radiator) or radiation between adjacent slots will not be in phase when they are separated by half of the guide wavelength. Arrays may be constructed using a plurality of radiators according to the first aspect of the invention.

According to a second aspect of the invention there is provided an antenna array comprising two or more elongated waveguide radiators each of which in cross section is divided into first and second waveguide portions by a septum, has a plurality of first elongated slots in an external wall of the radiator each of which extends on both sides of the septum and is orthogonal to the longitudinal axis of the radiator, and has a plurality of elongated second slots, each of which extends from a corresponding one of the first slots into the septum, wherein the separation between the first slots in each radiator is substantially equal to $\sqrt{10}$ times the distance from any first slot in the array to the nearest adjacent first slot.

In both first and second aspects of the invention the first and second waveguide portions are usually excited in antiphase.

Certain embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:-

Figure 1 is used in explaining radiators according to the invention and shows part of a waveguide,

Figure 2 shows a radiator according to the invention,

Figure 3 is a schematic diagram showing how phase reversal occurs between the slots of Figure 2,

Figure 4 shows another radiator according to the invention,

Figure 5 shows ways of stacking radiators to form arrays according to the invention, and

Figure 6 shows a way of feeding antenna arrays according to the invention.

In Figure 1 part of a slotted waveguide radiator 10 comprises two waveguides 11 and 12 each of the usual dimensions required to support the TE_{10} mode and thus for the X-band the breadth of the waveguide 10 is about two and a quarter centimetres while its overall height is in the region of two and a half centimetres. Thus the radiator 10 can be regarded as being bifurcated along the H plane. There are two slots 13 and 14 in the sidewall of the part of the waveguide radiator shown and a septum 15 separating the waveguides 11 and 12 has slots 16 and 17 contiguous with the slots 13 and 14, respectively. The slots 13, 14, 16 and 17 are part of a series of such slots along the radiator 10. For an X-band array the slots are about 0.2 cm wide and spaced at about 4.5 cm along the radiator.

Since slots 13 and 14 are orthogonal to the direction of propagation they would not radiate in a waveguide having no septum and further if the waveguides 11 and 12 were excited in phase the septum 15 would have no effect. Thus the waveguides 11 and 12 are normally excited in antiphase, so that the septum slots 16 and 17 are strongly excited by the "odd" TE_{10} mode since they significantly interrupt the septum wall currents of this mode. The fields produced in the slots 16 and 17 if they are each about a quarter of the free space wavelength long induce field patterns in the slots 13 and 14 causing them to radiate parasitically. However these slots can vary in length in the range one-eighth to half a free space wavelength. The slots 13 normally have an overall length of half the free space wavelength at the centre of the band to be propagated in the waveguides 11 and 12, although they may be as short as a quarter of the free space wavelength. Hence the slots 13 and 14 are resonant as are each upper half of the slots 13 and 14 together with the corresponding slots 16 and 17, and each lower half of the slots 13

and 14 together with the corresponding slots 16 and 17. Non-resonant slot lengths may be used if some pattern shaping is desired; for example a cosine distribution or other tapering of field strength across the antenna aperture. Other out of phase excitations than antiphase can sometimes prove useful for the waveguides 11 and 12.

The waveguide radiator 10 generates horizontal polarisation when the radiator is mounted horizontally, and as the slots 13 and 14 are orthogonal to the axis of the radiator, significant cross-polarisation does not occur. The slots 13 and 14 are regularly spaced and symmetrical with respect to the wall of the radiator 10 so periodic errors are avoided.

However a disadvantage of the arrangement of Figure 1 in comparison with conventional inclined-edge slot radiators is that 180° phase reversals between adjacent slots (to allow radiation in phase at half guide wavelength slot spacing) is not possible since such reversal is usually obtained by oppositely inclining alternate slots. Thus for a waveguide having a normal broadwall dimension, substantially more than one free space wavelength spacing between slots is required to procure approximately broadside radiation and as a result more than one principal radiation lobe occurs, that is grating lobes are formed.

The grating lobe problem can be largely overcome by the waveguide of Figure 2. This waveguide also has slots 13 and 14 but these slots radiate in phase when separated axially by half of one guide wavelength and so reduces the problem of grating lobes. As before the waveguides 11 and 12 are fed in antiphase but now septum slots 25 and 26 extend axially along the radiator 10 from the slots 13 and 14, respectively, and are configured to provide the required phase reversal. At each slot 13, 14, the direction in which the slots 25, 26 extend in the axial direction of the radiator 10 is reversed. Referring to Figure 3 where currents in the septum 15 are indicated by chain dashed arrows 27, the electric fields parasitically excited in the slots 25 and 26 are as shown by the arrows 28 and 29, respectively. Between two adjacent slots

two 180° phase changes occur, one because the slots are separated by half a guide wavelength and one due to the directions of the slots 25 and 26. It can be seen that the electric field directions excited in the slots 13 and 14 are in phase due to these two reversals and at half guide wavelength spacing, therefore, the slots radiate in phase. Again the slots 25 and 26 are each approximately a quarter of a free space wavelength long at the centre of the band of frequencies to be propagated and other dimensions are the same as those of the waveguide of Figure 1.

Since the slots 13 and 14 remain at right angles to the direction of propagation the problem of cross-polarisation is largely avoided and since the slots are symmetrical in relation to the centre line of the waveguide radiator no significant periodicity error arises in the beam pattern.

As shown in Figure 4, the septum slots 25 and 26 may be inclined to the longitudinal axis of the waveguide at angles up to, but not including, 90° (when they become equivalent to the slots 16 and 17). Traversing the waveguides in the longitudinal direction the slots are inclined first in the 'forward' direction and then in the 'backward' direction for adjacent slots. Such slots provide only partial phase reversal and although such a phase change is usually a disadvantage, it can sometimes be useful to give control of radiation strength if it is required to keep the lengths of the sidewall slots and septum slots invariant; for example in constructing a narrow-band resonant array.

For slot arrays for which a phase reversal mechanism is not possible, as with the radiator of Figure 1, the grating lobe problem can also be largely overcome by stacking radiators. Figure 5 shows three possible ways 20, 21 and 22 of stacking, on a background of equilateral triangles each having sides d. Schemes 20 and 21 are particularly suitable for this purpose. In each of the three stacked arrays shown, slots as indicated by lines transverse to the waveguides are separated by a distance d. The object of stacking is to create a planar array in which slots radiate in phase and are spaced by less than 0.7 λ_o, where λ_o is the free

space wavelength. This condition avoids grating lobes within + or - 90^{o} of the normal to the axes of the waveguides, allows a finite beam width and avoids large internal reflections within the waveguides. Thus d should be less than 0.7 λ_o but for simplicity this condition can be expressed as d approximately equal to $\lambda_{o/2}$. The array 20 is made up of three radiators 10 of the type shown in Figure 1 while the arrays 21 and 22 are each formed by two such radiators but, in practice, arrays of this type usually comprise many more radiators. Corresponding waveguides in the radiators making up the arrays are fed in phase.

In the array 20 the separation between adjacent slots in the same waveguide radiator is d $\sqrt{10}$ and thus the separation d between slots in the stacked array is just over a third of the guide wavelength (λ_g). Since the λ_g is greater than λ_o, d is, as required, approximately equal to $\lambda_{o/2}$. If the waveguide width is chosen to be that of a standard waveguide the direction of the beam is almost broadside. However as is apparent from Figure 5 this increase in slot separation is achieved at the expense of the sidewall dimension (b) of the waveguide radiator. As a consequence the sidewall dimension has to be reduced to less than 0.2 of a free space wavelength. After provision is made for wall thickness and the septum, the inside dimension of each waveguide 11 and 12 is such that manufacture is difficult.

The array 21 overcomes this problem but requires the addition of phase compensation between adjacent slots to reduce λ_g to be equal to or a little larger than λ_o in order to place the main beam close to broadside. The separation between the slots in each waveguide radiator making up the array is about λ_o giving the required array slot separation of about $\lambda_{o/2}$. Phase compensation can be obtained for example by dielectric loading (this is partially or completely filling the waveguide with dielectric), the use of periodically spaced metallic fins or irises, oversize waveguides or discrete phase shifters. The latter is usually preferable in view of attenuation loss, weight associated with

dielectric or periodic loading and overmoding associated with an oversize waveguide. If the individual waveguide radiators are of standard width then the required additional phase shift between slots which is needed to ensure approximately broadside radiation is of the order of 90°. Since the separation between adjacent slots is approximately one free space wavelength, sufficient space is available for the insertion of an inductive post phase shifter between slots.

In the array 22 the sidewall dimension b is enlarged to normal size. For slot arrays containing no phase reversals this arrangement requires that the waveguide radiator be even more heavily loaded so that λ_g approaches $\lambda_{o/2}$. While radiators as used in the arrays 20 and 21 are not suitable for use individually those of the array 22 may be used singly.

The array 20 can be fed in the way shown in Figure 6. A feed waveguide 31 has three slots which couple into bifurcated waveguides 32, 33 and 34 by way of 3dB power splitters 35, 36 and 37. Since the power splitters introduce a 90° phase shift between the two portions of each bifurcated waveguide, the upper portions include phase shifters 38, 39 and 40 to give the 180° phase difference to induce the "odd" mode in the waveguides. The phase shifters may comprise shaped dielectric inserts providing 90° of phase shift at the centre-band frequency but which are also matched to the waveguides. Matched loads 42 to 48 are provided for the waveguides 31 to 34. Other radiators according to the invention can be fed in similar ways.

Arrays 21 and 22 are more easily implemented with waveguide radiators of the type shown in Figures 2 and 4 since loading is not required. The distance S between slots in each radiator is, in effect, $\lambda_{g/2}$, and for the array 21 λ_g should equal about twice λ_o. This condition can easily be met for example by operating close to the cut-off frequency of the waveguide. For the array 22 if d is allowed to become equal to 0.7 λ_o then λ_g should be approximately 1.4 λ_o which again can easily be arranged.

It will be realised that there are many other ways of putting the invention into effect than those specifically described. For example the slots in the septum between the waveguides can be of other shapes provided, as far as the arrangement similar to Figure 3 are concerned, the electric field and adjacent slots are in opposite directions.

The waveguides may be filled with dielectric or may be periodically loaded to reduce the guide wavelength, thus minimising the grating lobe problem and also permitting frequency scanning of the main radiated beam. The sidewall slots and the septum slots may be considerably shorter than their 'resonant' values if a particular aperture field shaping is desired. The slots in the waveguide walls may extend from the narrow walls into the broad walls.

CLAIMS

1. An elongated waveguide radiator which in cross section is divided into first and second waveguide portions by a septum, having a plurality of first elongated slots in an external wall of the radiator each of which extends on both sides of the septum characterised in that each second slot is orthogonal to the longitudinal axis of the radiator, and a plurality of elongated second slots, each of which extends from a corresponding one of the first slots into the septum, characterised in that each second slot has a longitudinal axis which is inclined to a line in the septum normal to the longitudinal axis of the radiator, the direction of the angle of inclination alternating along the radiator.

2. A radiator according to Claim 1 characterised in that the angle of inclination is 90^{o}.

3. A radiator according to Claim 1 or 2 for use in a predetermined frequency range characterised in that each first slot is between a quarter and half a free space wavelength long at the centre frequency of the range.

4. A radiator according to any preceding claim for use in a predetermined frequency range characterised in that each second slot is between one-eighth of and half a quarter of a free space wavelength long at the centre frequency of the range.

5. A radiator according to any preceding claim characterised in that the first and second waveguide portions are of rectangular internal cross-section.

6. An antenna array comprising a plurality of waveguide radiators characterised in that each radiator is according to any preceding claim.

7. An antenna array comprising two or more elongated waveguide radiators each of which in cross section is divided into first and second waveguide portions by a septum, has a plurality of first elongated slots in an external wall of the radiator each of which extends on both sides of the septum and is orthogonal to the longitudinal axis of the radiator, and has a plurality of elongated second slots, each of which extends from a corresponding one of

the first slots into the septum, characterised in that the spacing between the first slots in each radiator is substantially equal to $\sqrt{10}$ times the distance from any first slot in the array to the nearest adjacent first slot.

8. An antenna array according to Claim 7 characterised in that the first and second waveguide portions are totally or partially filled with dielectric or contain periodically spaced metallic fins or irises.

9. An antenna array according to Claim 7 or 8 for use in a predetermined frequency range characterised in that each first slot is between a quarter and half a free space wavelength long at the centre frequency of the range.

10. An antenna array according to any of Claims 7 to 9 for use in a predetermined frequency range characterised in that each second slot is between one-eighth of and half free space wavelength long at the centre frequency of the range.

11. An antenna array according to any of Claims 7 to 10 characterised in that the first and second waveguide portions are of rectangular internal cross-section.

12. An antenna array according to any of Claims 6 to 11 characterised by means for feeding each said radiator by way of a respective waveguide feed, each said radiator including a power splitter for supplying signals for the first and second waveguide portions from the waveguide portion of that radiator, and a phase shifter for ensuring a predetermined phase difference between the first and second waveguide portions of that radiator.

13. An antenna according to Claim 12 characterised in that the predetermined phase difference is 180°.

14. An antenna array comprising at least one waveguide radiator having sidewall slots which, in operation, radiate and together generate a radiation pattern which is substantially free of grating lobes.

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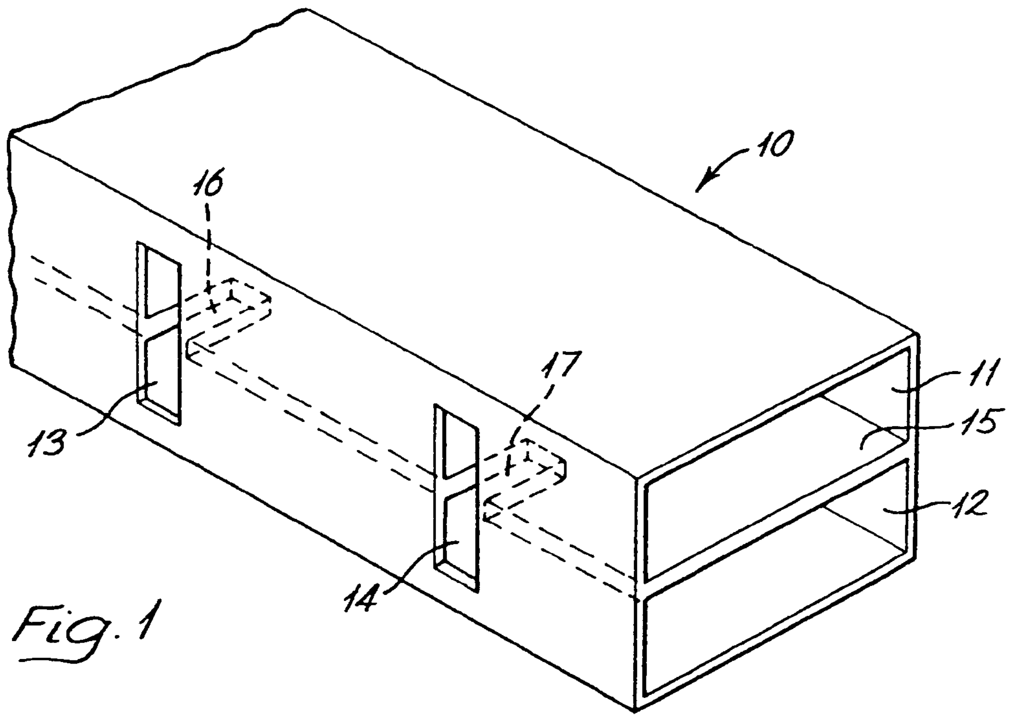

Fig. 1

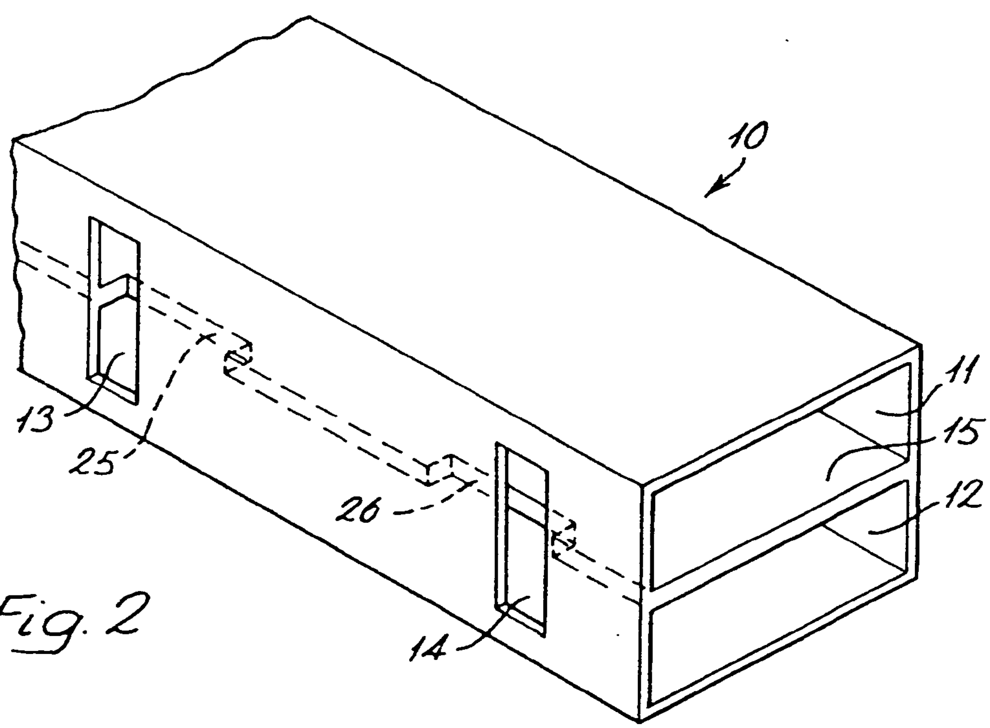

Fig. 2

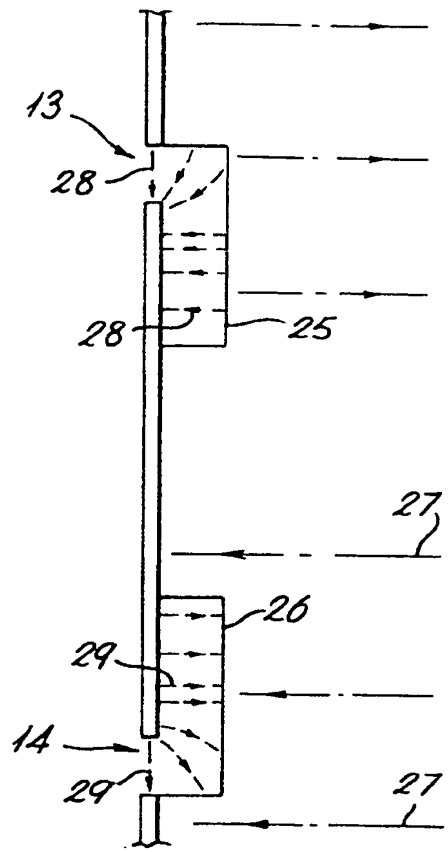

Fig. 3

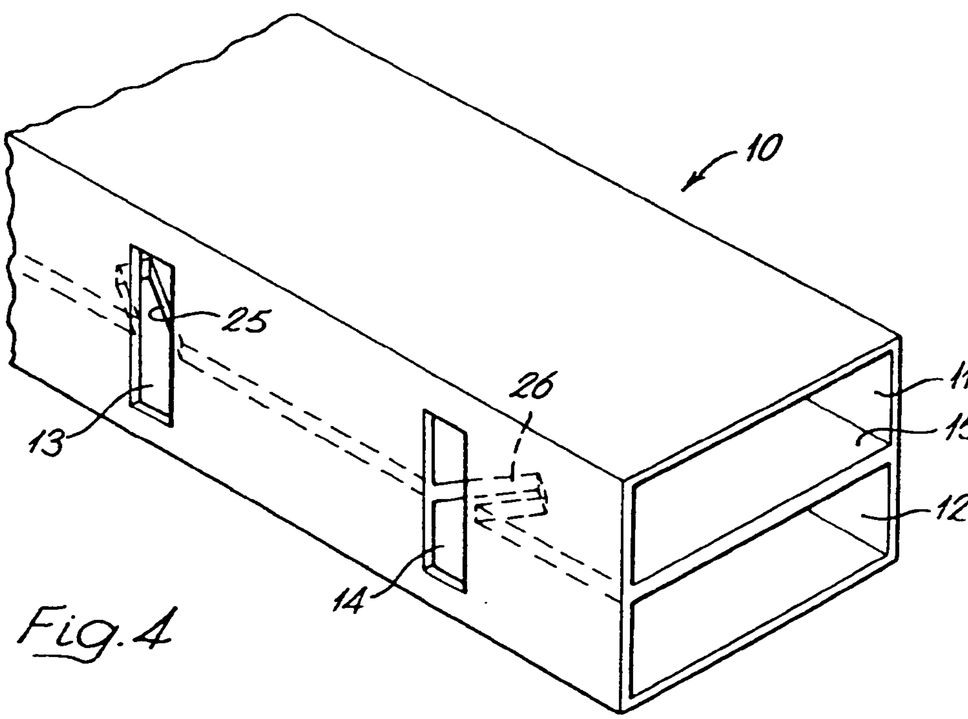

Fig. 4

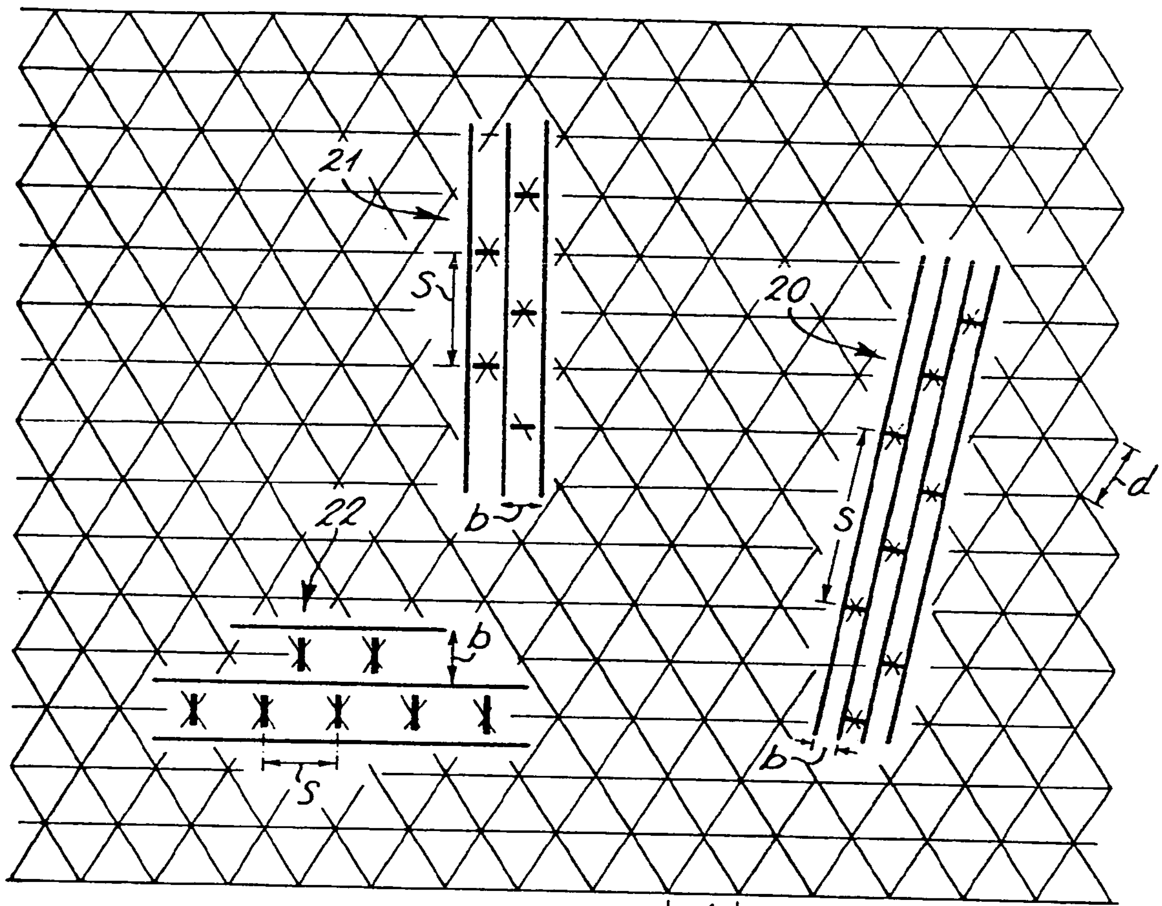

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Fig. 5

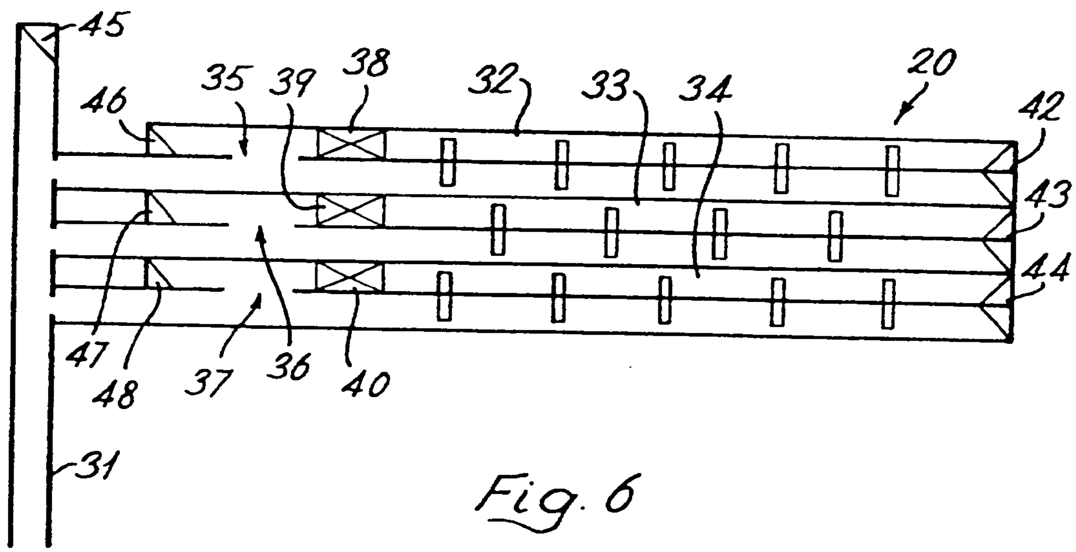

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Fig. 6

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(54) **Slotted waveguide antennas and arrays.**

(57) Array antennas constructed from some forms of waveguide radiators with sidewall slots exhibit cross polarisation and periodic errors. This problem arises from the difficulty of obtaining phase reversal in the radiation from adjacent slots in such a radiator other than by slot inclination. The present invention offers two solutions. Firstly, a radiator (10) having a number of non-inclined sidewall slots (13, 14) and a septum (15) with inclined slots (25, 26) which provide a phase relationship in the radiation from the sidewall slots which ensures that no significant cross polarisation errors nor grating lobes occur. A number of radiators (10) can be used to form an array. Secondly, arrays using radiators with sidewall slots, in which the distance between these slots, the dimensions of the radiators and the relative positions of individual radiators are such that the phase relationships in radiation from the slots of the array prevent significant grating lobes.

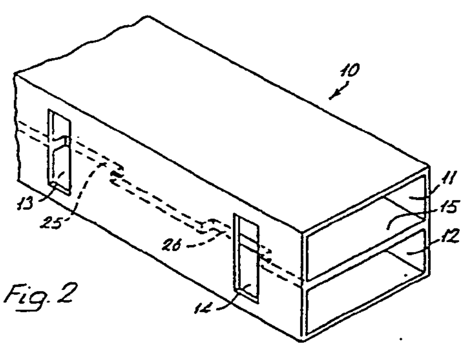

Fig. 2

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EUROPEAN SEARCH REPORT

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Application Number

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y	IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, vol. AP-32, no. 3, March 1984, pages 247-251, IEEE, New York, US; J.S.AJIOKA et al.: "Slot radiators in septated waveguide" * Page 249, left-hand column, line 4 - page 250, right-hand column, line 25 and lines 53-58; figures 2,4-6 *	1,2,5,6	H 01 Q 21/06 H 01 Q 13/10
Y	US-A-3 720 953 (AJIOKA) * Abstract; column 3, lines 14-62; figures 2,3a,5,7; claims 1-15 *	1,2,5,6	
A		7-14	
A	IEEE TRANSACTIONS OF ANTENNAS AND PROPAGATION, vol. AP-22, no. 2, March 1974, pages 196-200, IEEE, New York, US; J.AJIOKA et al.: "Arbitrarily polarized slot radiators in bifurcated waveguide arrays" * Abstract; pages 198-200; figures 2-5 *	1,6,7, 12-14	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	IEE PROC., vol. 129, Pt. H, no. 6, December 1982, pages 299-306; A.J.SANGSTER et al.: "Moment method analysis of a T-shaped slot radiator in bifurcated waveguide" * Page 299; figure 1b; pages 303-305; figures 4-6 *	1-5	H 01 Q
A	DE-A-1 441 741 (LABORATORY FOR ELECTRONICS) * Claims 1,2 *	7	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	09-05-1988	ANGRABEIT F.F.K.

CATEGORY OF CITED DOCUMENTS

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